

“Intensity Frontier Report:” DUNE (LAr) Reconstruction

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Computing Frontier Workshop

August 10th, 2020

- Background
- DUNE reco. overview
- Challenges
- Parting thoughts

Who am I?

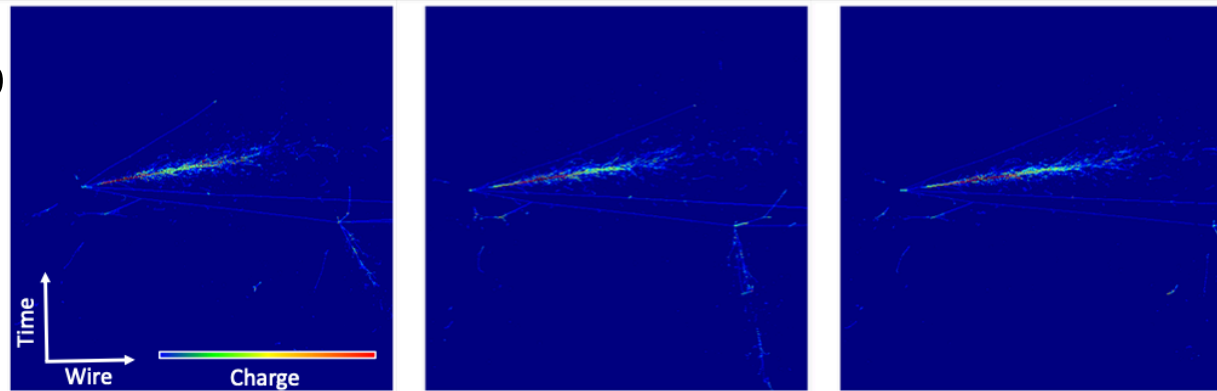
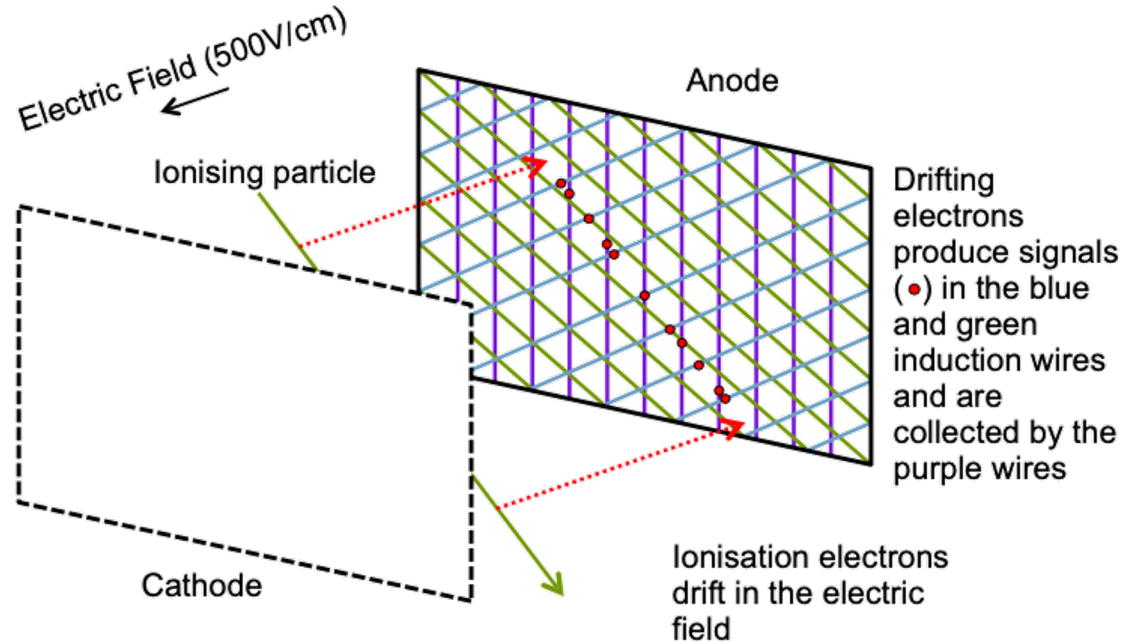
- My background:
 - Long baseline experiments (MINOS, T2K/SK, NOvA, DUNE)
- NOvA
 - Computing Coordinator, then Analysis Coordinator
 - Overseeing reco group as well as production group
 - Deep-learning (CNN) particle IDs
- DUNE
 - DUNE Simulation/Reconstruction convener
 - Single-Phase Photon Detection Simulation + Physics convener
 - Oversaw development of large parts of our photon detector simulation and reco.

Orientation

- Reconstruction challenges in the entirety of the Intensity Frontier is way beyond what I can cover!
- First, “Intensity” is now divided into two frontiers:
 - Neutrinos
 - Rare Processes and Precision
- Even in Neutrinos, there’s wide variety:
 - Reconstruction in Water Cherenkov detectors (SK, T2K)
 - Reconstruction in Frequency Space (Project 8)
 - Non-TPC Tracking detectors (MINOS, NOvA, Minerva)
 - Argon TPC Reconstruction
- Even within DUNE, there’s wide variety:
 - Single-phase LArTPC with 3 wire views
 - Dual-phase LArTPC with 2 strip views
 - Single-phase LArTPC with pixel readout
 - Magnetized Gaseous Argon TPC
- I will focus on reconstruction challenges for DUNE, largely single-phase 3 wire view, but I will generalize where possible.

LAr TPCs

- Large, \sim homogenous detectors.
- Tracking calorimeters.
 - Event topology
 - Reconstruct total energy.
- Charged particles ionize the argon, a strong electric “drifts” charge to the readout planes.
- Each wire plane gives a 2D view in time vs. wire.
- Step through the reconstruction stages, and challenges, starting from the raw events.

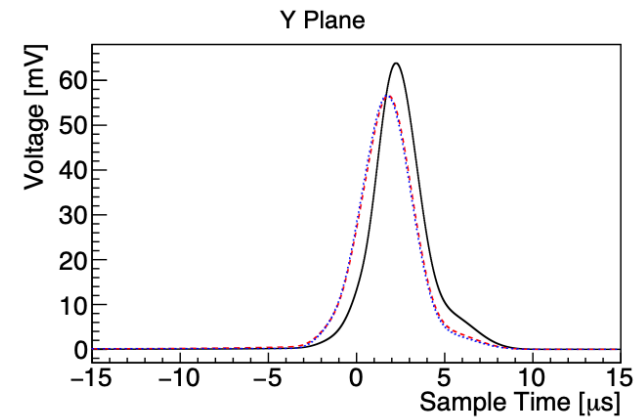
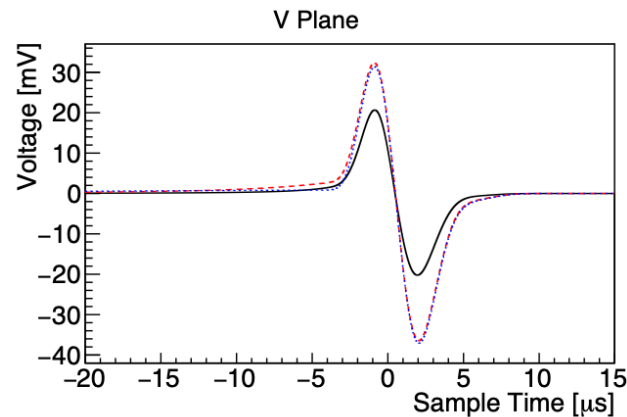
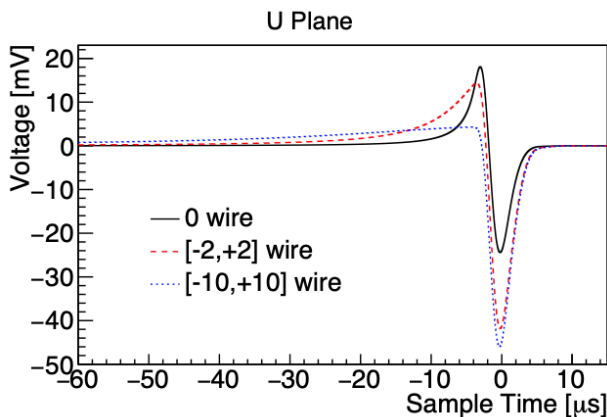


What are raw DUNE events like?

- DUNE has a very different challenge from colliders:
 - A Hz-scale rate of very large events instead of a very high rate of small events.
- Neutrino events
 - Neutrino beam spills arrive at a rate 0.5-1 Hz.
 - TPCs are slow detectors: while the spill is $\sim 10 \mu\text{s}$, the time to drift the electrons is 5.4 ms.
 - Leads to 6 GB events (2-3 GB with compression)
- Supernova bursts
 - Rare (we require a fake trigger rate of $< 1/\text{month}$)
 - Continuous readout for 100 seconds – 180 TB
 - 4-5 hours to transfer out of the mine
- Raw data handling puts particular pressure on the design of the software framework.
 - We use ART, which branched off from CMSSW some time ago.
 - Work is underway now to support handling only parts of events in memory at one time.

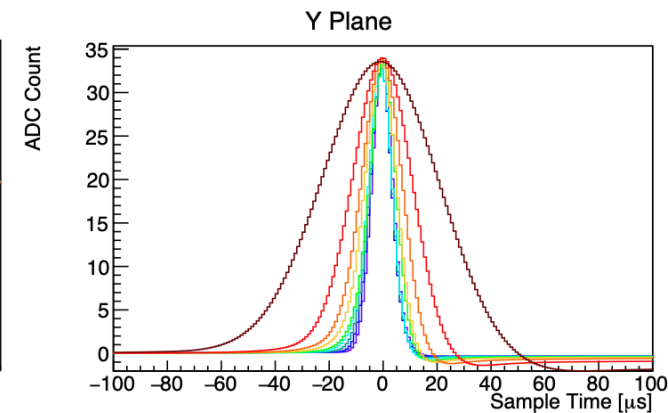
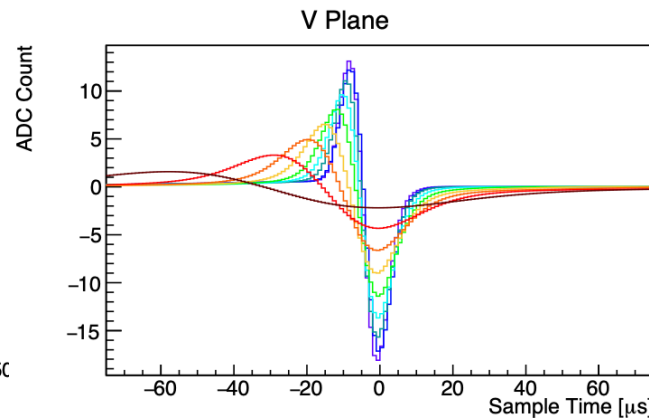
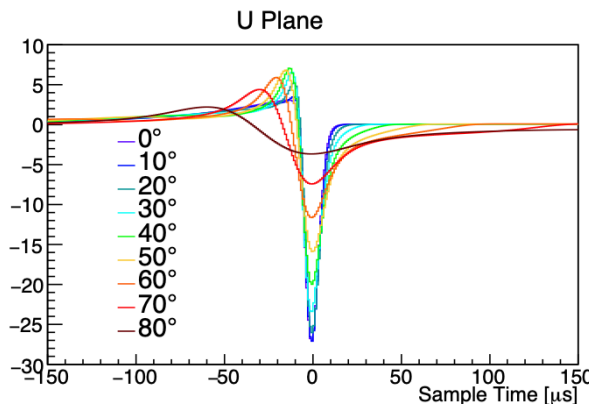
First Reconstruction Stages: Hits and ROIs

- First challenge: identifying regions of interest and hits.
 - 2 different kinds of wires – induction planes have bipolar signals, collection plane has a unipolar signal.
 - Bipolar hit finding is a particular challenge in resource-limited environments like the trigger.
- Some inconvenient reality:
 - The electric field is not perfectly uniform
 - Charge can disperse across multiple wires

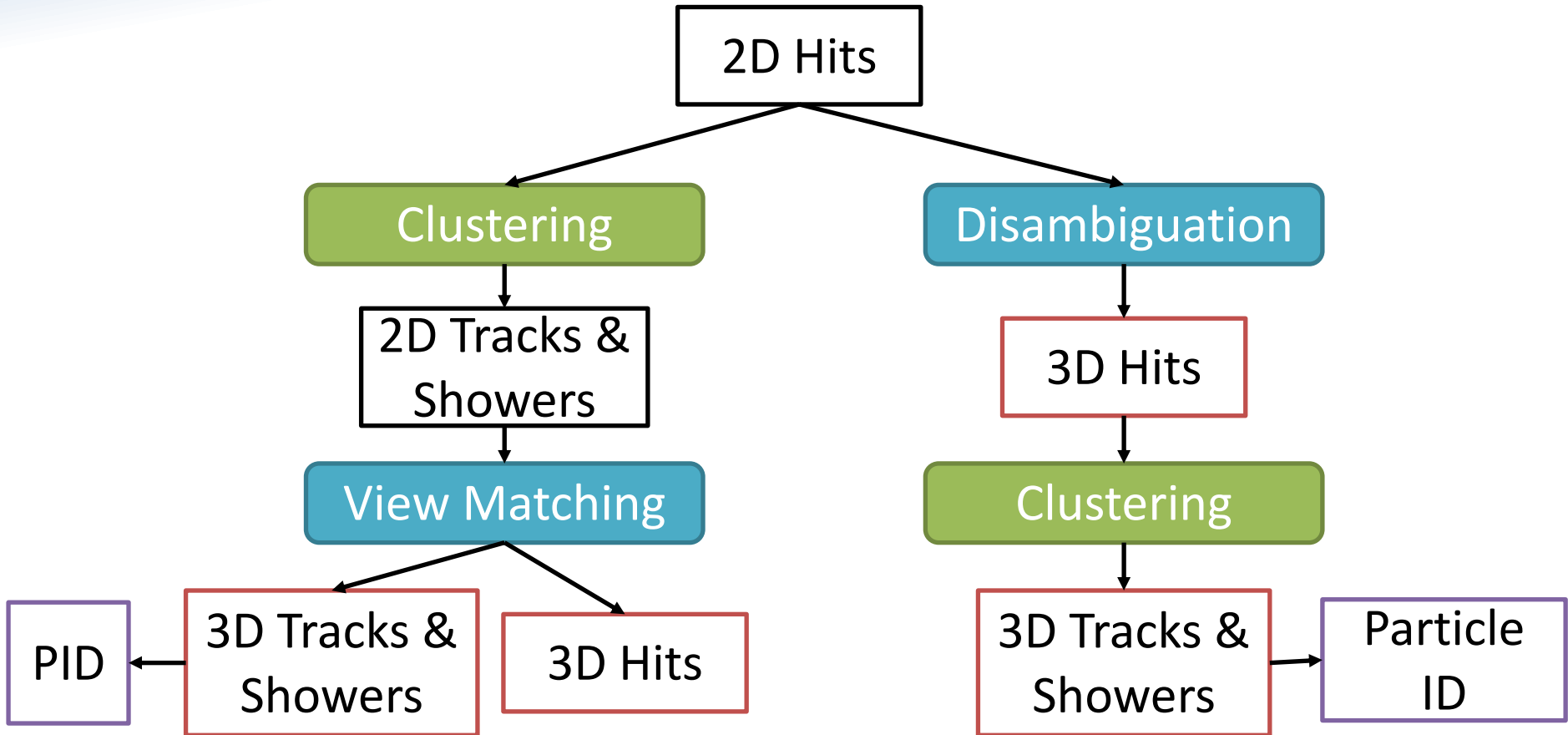


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- Some inconvenient reality:
 - The electric field is not perfectly uniform
 - Charge can disperse across multiple wires
- Non-ideal hits
 - If a track aligns with a wire direction, the whole track becomes a single large hit in that view.
 - If a track aligns with the drift axis, it creates a very “long” hit.

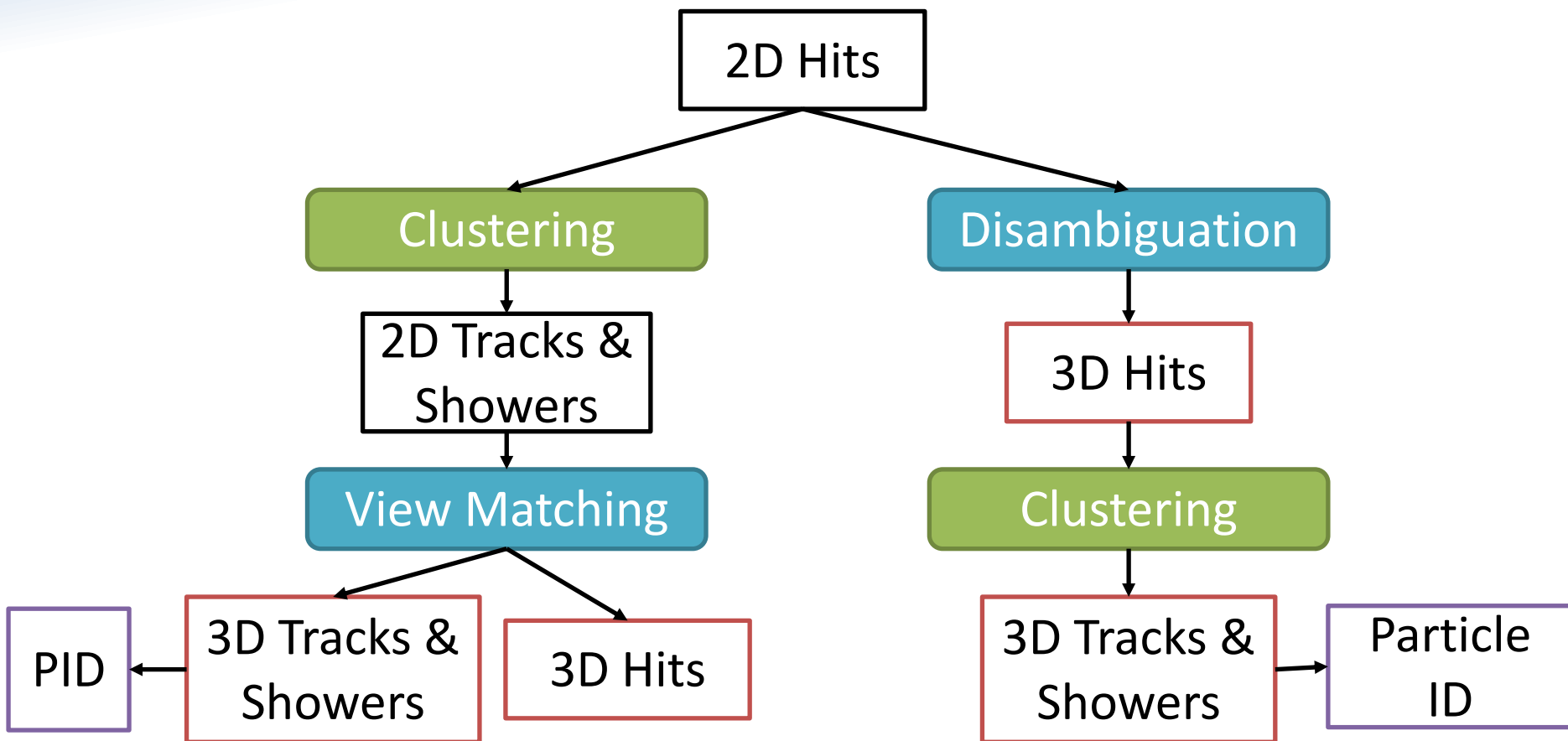


2D Hits → 3D Objects



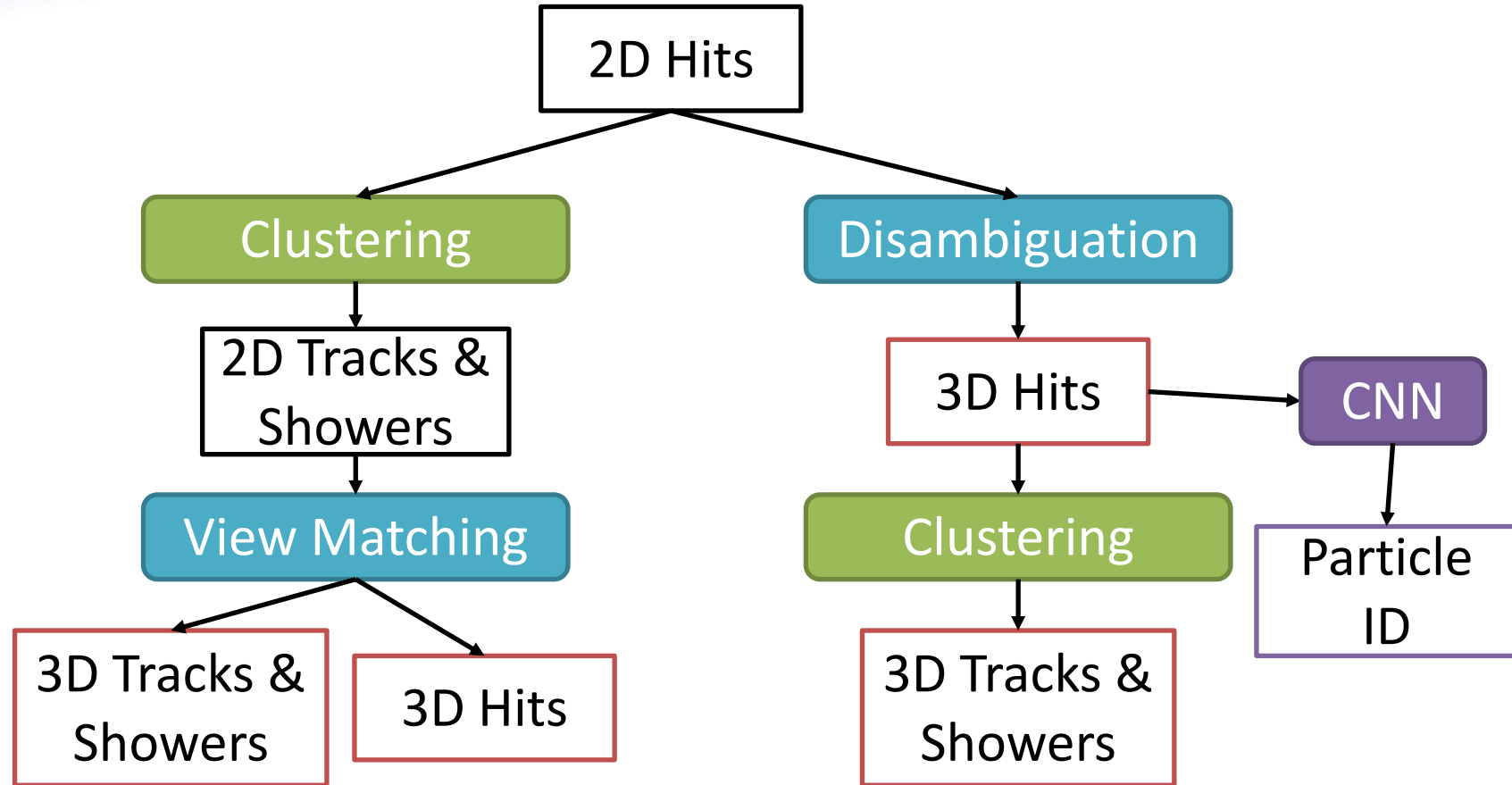
- We need to eventually get to 3D reconstructed objects.
- 2 different paths thinking about “traditional” reconstruction.

2D Hits → 3D Objects



- We need to eventually get to 3D reconstructed objects.
- 2 different paths thinking about “traditional” reconstruction.
- Reality is somewhat more complicated!

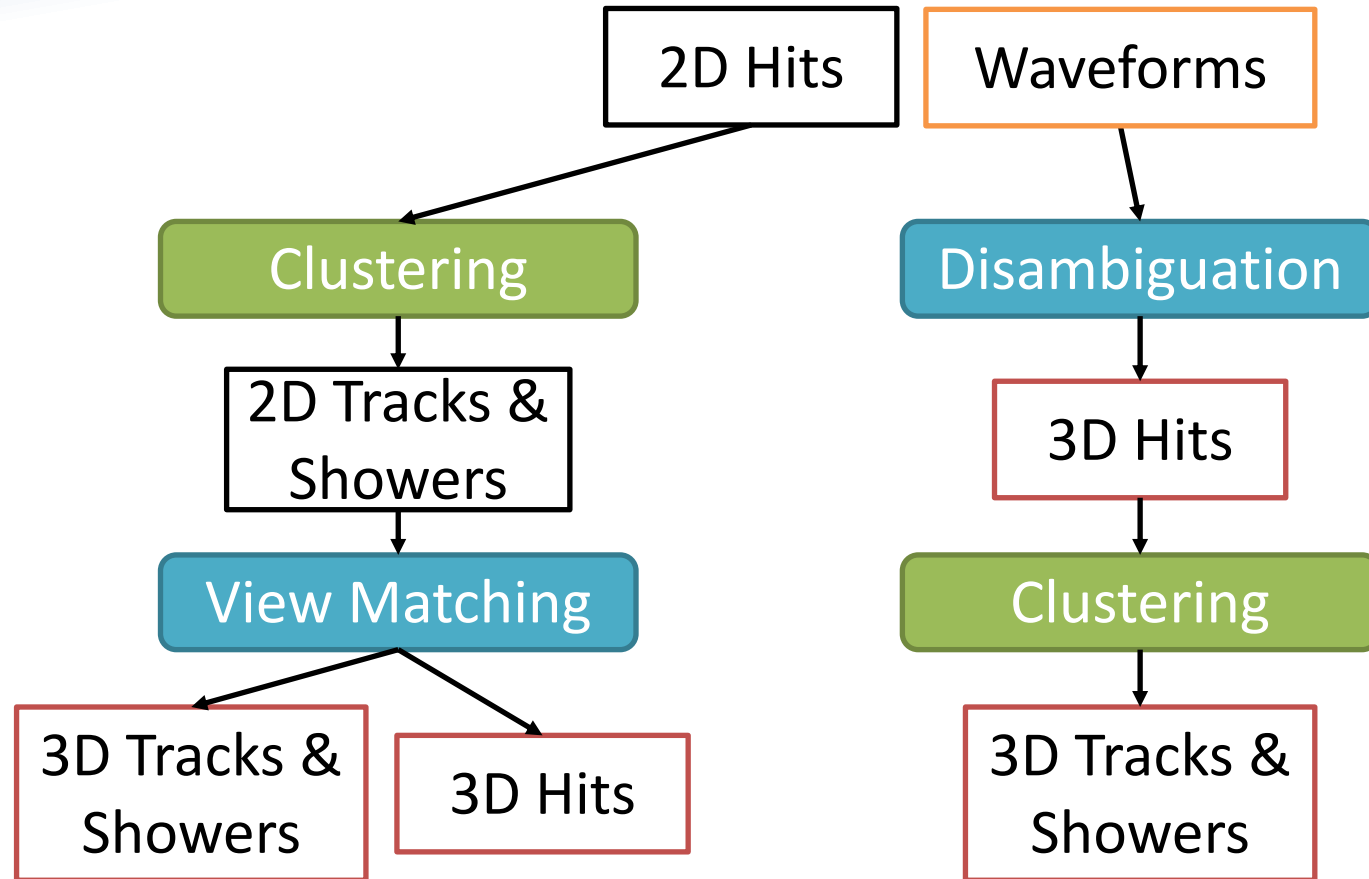
2D Hits → 3D Objects



“CVN”

arXiv:2006.15052

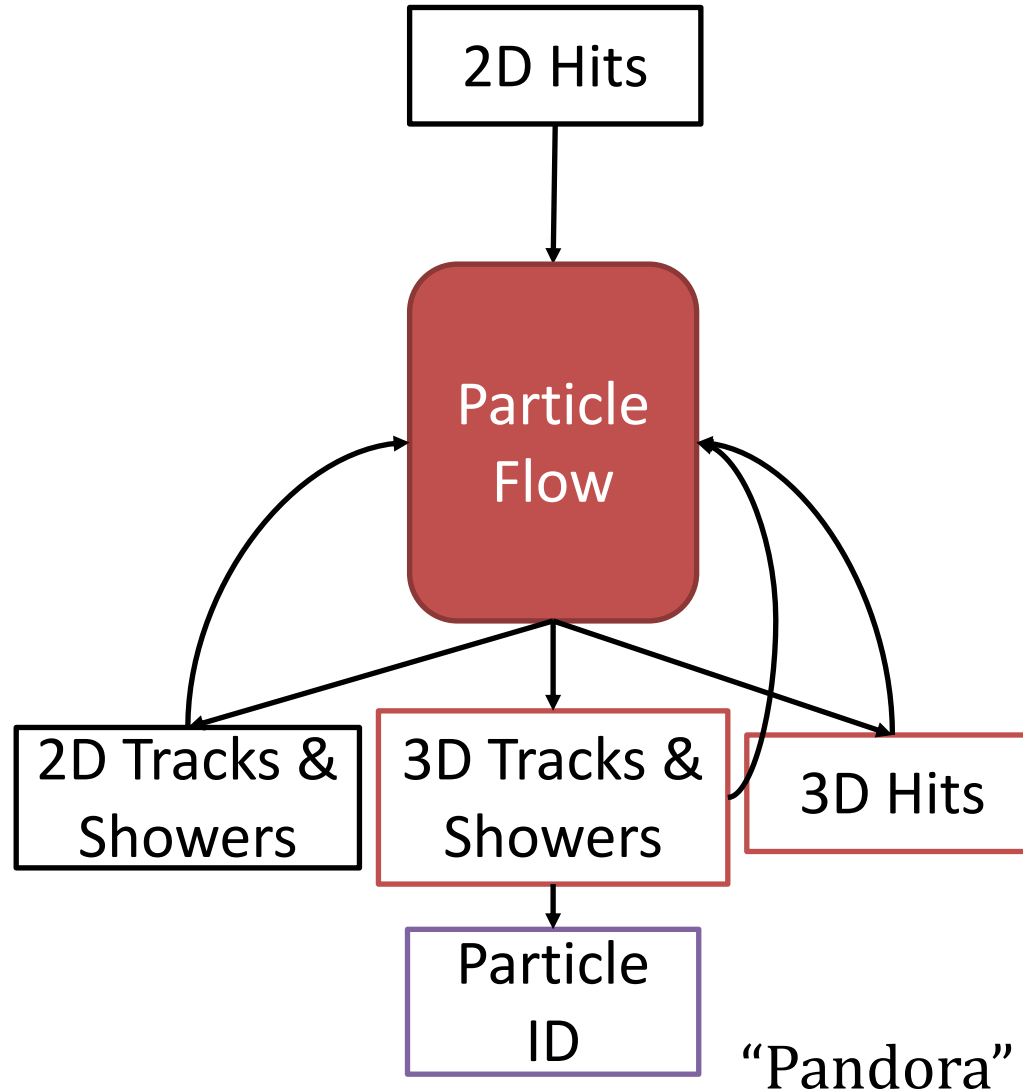
2D Hits → 3D Objects



“Wirecell”

JINST 13 P07006/7 (2018)

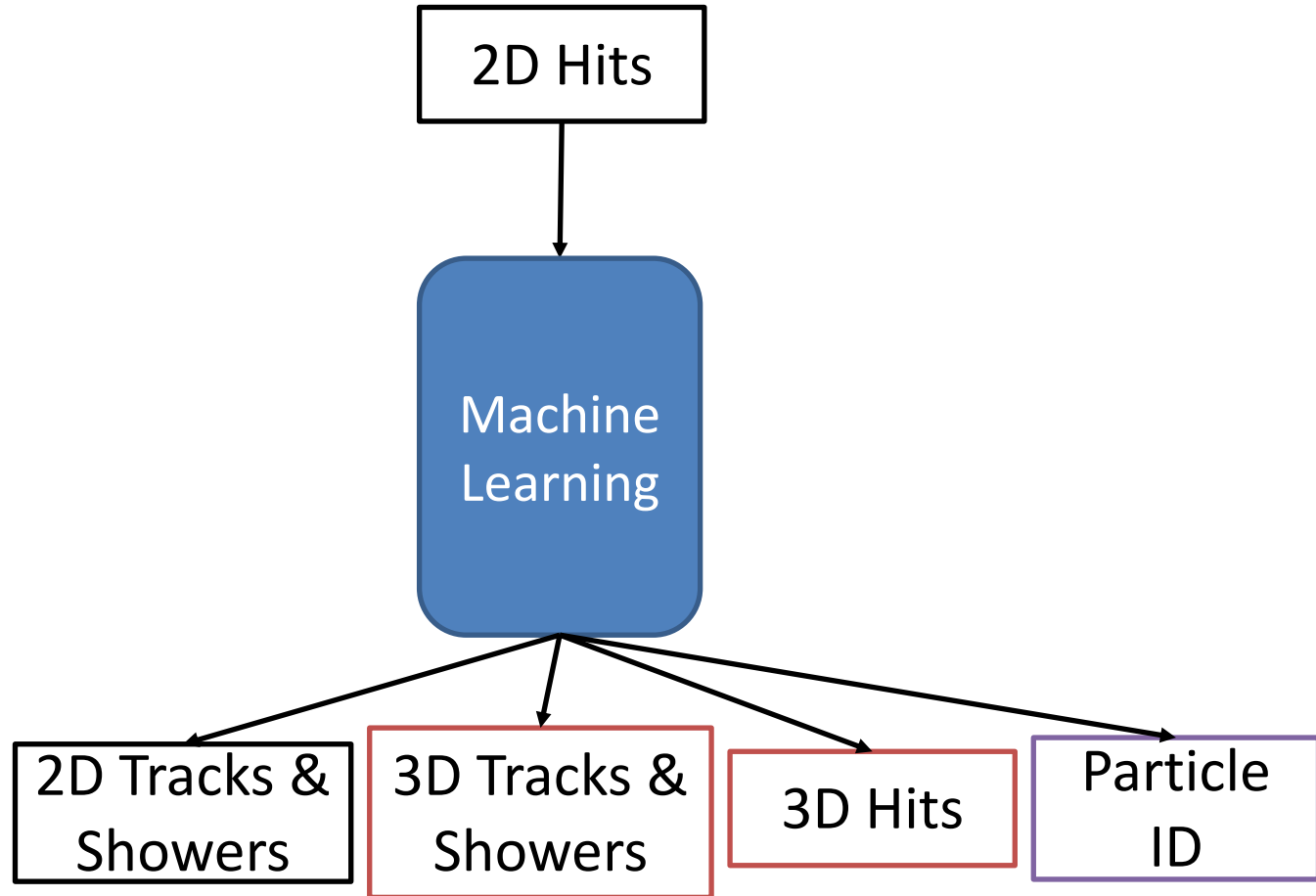
2D Hits → 3D Objects



"Pandora"

arXiv:1708.03135

2D Hits → 3D Objects

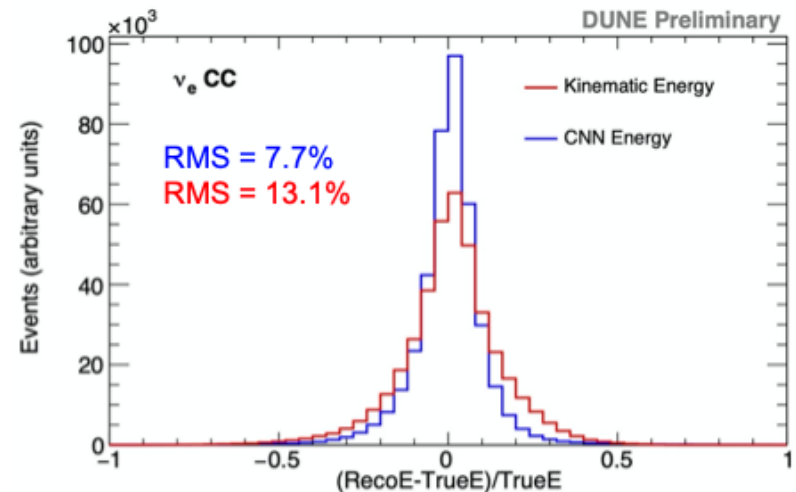
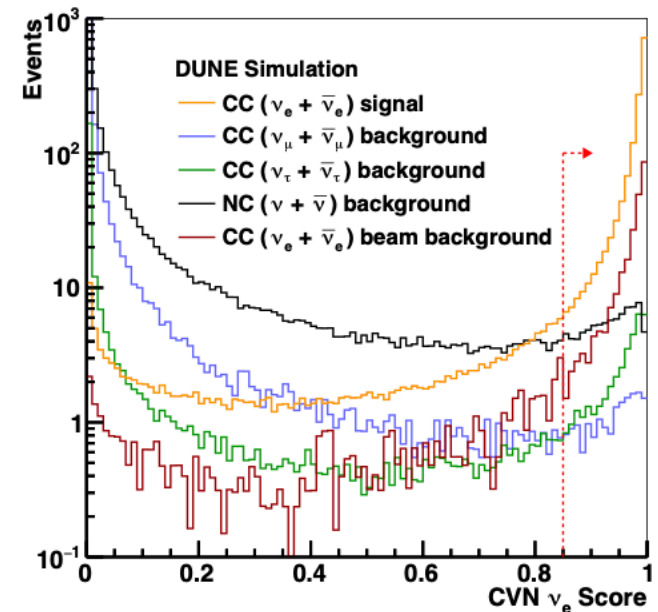


ML techniques

JINST 12, P03011 (2017)
Phys. Rev. D 99, 092001 (2019)

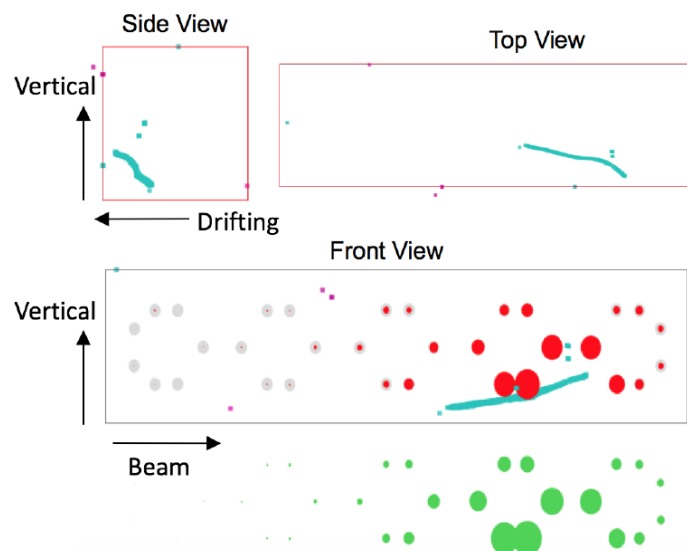
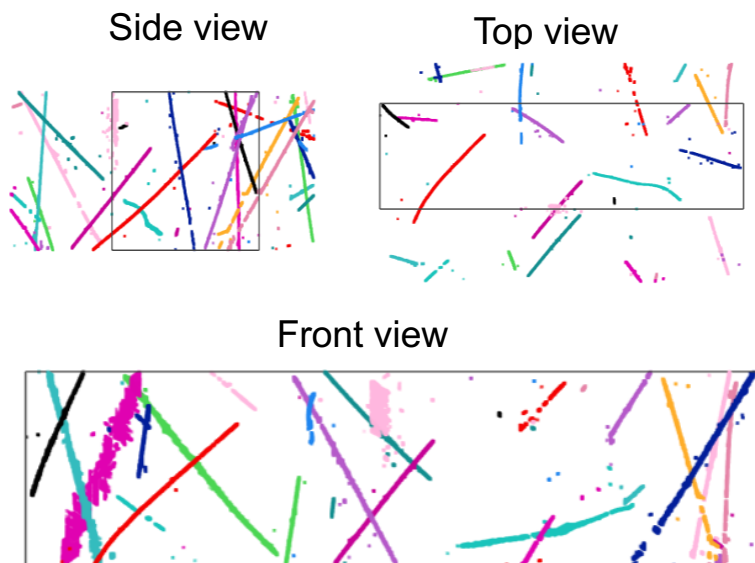
3D Objects → Physics

- Physics generally requires determining some or all of:
 - Neutrino flavor ID
 - Find and identify primary lepton
 - In particular: separate π^0 from e^\pm and μ^\pm from π^\pm
 - Total neutrino energy
 - Final-state particle composition and kinematics
- Can be done with “traditional” methods:
 - Likelihoods, EM vs. Had calorimetry, track length
- Can also be done with Deep Learning:
 - CNNs, LSTMs, graph networks, etc.
 - Note: these high-level reco can “interact” with low-level reco, for example particle ID informing clustering.



Interaction between Simulation and Reconstruction

- One example is matching charge and light.
- Most LAr TPCs also include a photon detection system.
 - Lower spatial resolution, but *much* faster.
- Surface detectors use matching between charge and light to exclude cosmic rays.
- Best technique: rapidly re-simulate the light which would be produced by reconstructed objects for comparison.
 - Requires *fast* simulation of the photons.
 - How does the “reconstruction simulation” interact with the actual simulation?



Some Shared Challenges

- Determining 3D from 2D
 - Matching is in general ambiguous.
 - Techniques use “sparseness” and similar constraints.
- How to deal with the imperfections of prior “stages”:
 - Proceed as best you can (traditional)
 - Iterate (particle flow)
 - Optimize simultaneously (ML)
- Can the same (or very similar) techniques apply to different detectors within DUNE?
 - Some demonstration of CVN and Pandora working on dual phase FD and ND pixel detectors.
 - Needs of ProtoDUNE (surface, charged particles) vs. FD (underground, neutrinos)

Coordination Challenges

- Many different techniques being developed simultaneously in many overlapping spheres.
 - External frameworks: Pandora, Wirecell, ML (TF, Pytorch, etc.)
 - Different experiments with similar but distinct needs:
 - MicroBooNE, SBN, ProtoDUNE, Single and Dual phase FD, DUNE-ND
- How do we avoid “monolithic” competition?
 - Different algorithms may do better at different parts of the reconstruction chain.
 - Can we enforce “break points?” How do they interact with “iterative” approaches?
 - How many “parallel” reconstruction chains can we afford to run in production?

Coordination Challenges

- How do we make efficient use of resources with heterogeneous reconstruction algorithms?
 - Imagine a workflow where 75% of CPU time is spent running deep learning algorithms.
 - Can dramatically speed up by moving to resources with GPUs, but if it is a mixed algorithm the GPU may only be used for a small fraction of the job time.
 - Client-server model? Requires development and requires over-resourcing (or dynamic resourcing) the expensive GPUs.
- This happens on a smaller scale when different algorithms support different levels of parallelism.
 - How strictly do we need to enforce multi-threading support?
 - It imposes cost on the people developing algorithms and may prevent the use of what would otherwise be useful tools.

Parting Thoughts

- This talk is primarily from the perspective of the DUNE single phase Far Detector, but generalizes with progressively less fidelity to:
 - Other single-phase LAr detectors (ex: SBN)
 - Other DUNE detectors (ex: dual phase)
 - Other tracking calorimeters for neutrinos (NOvA)
 - Other large neutrino experiments
 - ...and probably not much past that.
- There's a lot of cross-over here, particularly with ML (CF03) and facilities (CF04).
- I think there's a lot of opportunity to learn best practices from other frontiers/experiments.